



## The Focal Surface of the JEM-EUSO Telescope

THE JEM-EUSO COLLABORATION

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**Abstract:** "Extreme Universe Space Observatory onboard JEM/EF" (JEM-EUSO) is a space mission to study extremely high-energy cosmic rays. The JEM-EUSO instrument is a wide-angle refractive telescope in near-ultraviolet wavelength region to observe time-resolved atmospheric fluorescence images of the extensive air showers from the International Space Station. The focal surface is a spherical curved surface, and its area amounts to about  $4.5\text{m}^2$ . The focal surface detector is covered with about 6,000 multi-anode photomultipliers (MAPMTs). The focal surface detector consists of Photo-Detector-Modules, each of which consists of 9 Elementary Cells (ECs). The EC contains 4 units of the MAPMTs. Therefore, about 1,500 ECs or about 160 PDMS are arranged on the whole of the focal surface of JEM-EUSO. The EC is a basic unit of the front-end electronics. The PDM is a basic unit of the data acquisition system.

### 1. Overview

JEM-EUSO (Extreme Universe Space Observatory onboard Japanese Experiment Module) is a super-wide field UV telescope to detect Ultra-High Energy Cosmic-Rays (UHECRs) with energy above  $10^{20}\text{eV}$ [1]. JEM-EUSO started the preparation targeting the launch in 2013 in the framework of second phase of JEM/EF (Exposure Facility) utilization. The phase-A study of the EUSO (Extreme Universe Space Observatory) mission has been done from March 2003 through June 2004 under the supervision of European Space Agency (ESA) and the detailed report is written and accepted. We shall call this version of the EUSO telescope as ESA-EUSO.

The JEM-EUSO telescope instrument is divided into four parts[2]; those are optics, focal surface detector, focal surface electronics, and structure. The optics focuses the UV lights ( $330\text{nm}$ - $400\text{nm}$ ) incident to the front lens onto focal surface with the angular resolution of 0.1 degree[3]. The focal surface detector converts photon energy to an electric pulse. The focal surface electronics count-up the number of the electric pulse in the period of GTU (Gate Time Unit:  $2.5\mu\text{s}$ ) and records as a brightness of a pixel. When it finds a signal pattern came from Extensive Air Shower (EAS), it is-

sues trigger signal. It starts a sequence to send the all the brightness data close to the triggered pixels stored in the memory and send to the ground operation center. The structure encloses all the parts of the instruments and keeps them out from the outer harmful environment in the space. It also keeps the lenses and focal surface to the preset place. JEM-EUSO is designed to reduce the threshold energy of EAS down to as low as  $10^{19}\text{eV}$  and increase the exposure, keeping design of ESA-EUSO as baseline. The reduction of threshold energy may realize 1) new material and improved optics design, 2) higher quantum efficiency detector, and 3) improved trigger algorithms. The increase in exposure is realized by inclining the telescope from nadir (tilted mode). In this tilted mode, the threshold energy gets higher since the mean distance to EAS and atmospheric absorption both increase. First half of the mission lifetime is devoted to lower energy in nadir mode and second half of the mission to high energy by tilted mode.

In this paper, mainly, we report the changes of the focal surface detector and the electronics.

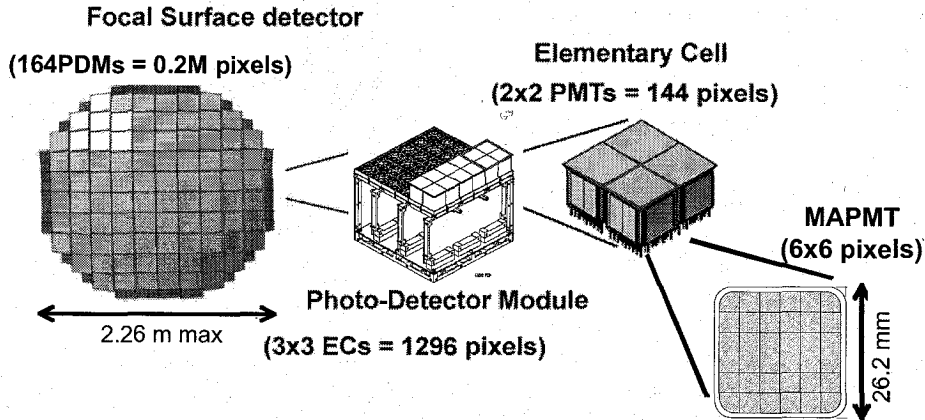


Figure 1: Focal surface detector and the structure.

## 2. Focal Surface Detector

### 2.1. Outline

The focal surface of JEM-EUSO has a curved surface of about 2.3m in diameter, and it is covered with about 6,000 multi-anode photomultiplier tubes (Hamamatsu R8900-M36[4]: MAPMT). The focal surface detector consists of Photo-Detector Modules (PDMs), each of which consists of 9 Elementary Cells (ECs). The EC contains 4 units of the MAPMTs. Therefore, about 1,500 ECs or about 160 PDMs are arranged on the whole of the focal surface (Figure 1). The high voltage power supply for the MAPMT is set one unit on every PDM. A photoelectron is multiplied to about  $10^6$  electrons in the MAPMT. The output pulse signals of the MAPMT are sent to ASICs (Application Specific Integrated Circuit) which are included in the front-end electronic circuits.

### 2.2. Focal Surface Detector for JEM-EUSO

Fundamental design of the JEM-EUSO focal surface succeeds the design of ESA-EUSO. Owing to the recent technological progress, the quantum efficiency of the MAPMT will be improved to about 0.3.

We are developing the high-voltage divider including a protection circuit. It protects the MAPMT

from an instantaneous large amount of light like the lightning. We can operate it safely by intercepting the photoelectron multiplication at the initial stage of the dynodes using a Photo-MOS relay.

Recently, Hamamatsu Photonics announced a high quantum efficiency technology for the bialkali photo cathode. This technology can be adapted to our MAPMT, R8900-M36. In this case, the quantum efficiency grows up about 0.4.

## 3. Focal Surface Electronics

### 3.1. Outline

The focal-surface electronic subsystem includes about 6,000 multi-anode PMTs to record, in time series, UV-light intensity emitted from EAS induced by ultra-high energy cosmic rays. The electronic system is required to keep a high trigger efficiency with a flexible trigger algorithm as well as a reasonable linearity over  $10^{19}$ - $10^{21}$  eV range. The requirement must be fulfilled with a power consumption of 2-3mW/ch to manage 200,000 signal channels in an available power budget. There exists some concern regarding on available volume for instruments and radiation tolerance of the electronic circuits in the space environment during a scheduled operation period. The phase-A feasibility study under ESA-ESO program covered almost every aspect of the ESA-EUSO mission based on

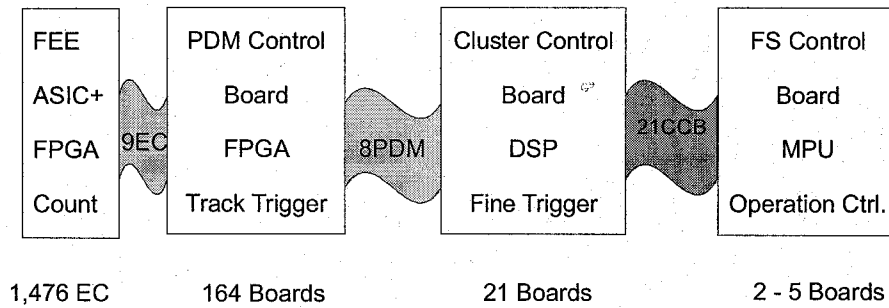


Figure 2: Outline of the data processing system.

proto-type fabrications to reveal that the above-mentioned requirements are reasonably satisfied.

### 3.2. Focal-Surface electronics for JEM-EUSO

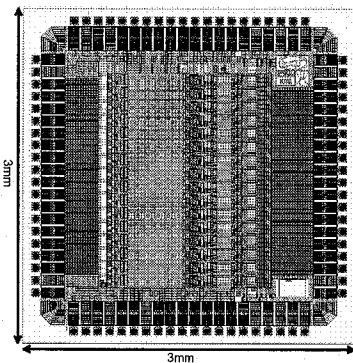


Figure 3: The ASIC design.

Inheriting the above-mentioned efforts and achievements concerning the phase-A study, the electronics of JEM-EUSO extensively employs ASICs, and, then, proceeds design to conform to power and volume constraints. By this way, we intend to refrain from a log-distance signal transmission as well as to reduce required power consumption. The Focal-Surface electronics for JEM-EUSO is composed of 4 hierarchies ; EC electronics, PDM control electronics, PDM cluster

(which consists with about 20 PDMs) control electronics, and focal-surface control electronics (Figure 2). JEM-EUSO extensively employs FPGAs (Field Programmable Gate Array) even for the readout and control boards to sophisticate the trigger algorithm without losing flexibility as well as to reduce required power consumption. The trigger logic of JEM-EUSO is planned to be a "Track trigger method". This method needs high calculation power, and we plan to use FPGAs and DSPs (Digital Signal Processor) for the trigger.

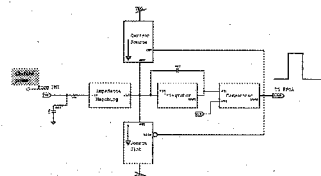


Figure 4: The block diagram of the ASIC

We have already made ASICs to evaluate its performance (Figure 3). The ASIC receive an analogue signal from PMT and send a digital signal which pulse width corresponds to the input charge (Figure 4). Now, we are confirming the performance.

### 3.3. Trigger Logic

To perform the effective trigger, the trigger logic of JEM-EUSO is planned to be a "Track trigger method", which searches the light point moving with almost the light speed at 400km ahead. The procedure of the track trigger method is the following.

- 1) The pixel with a high signal ( $\geq nR$ ) is defined as "Red Pixel" ( $nR$  is typically about 7.). Under the typical background light condition, the rate of the Red Pixel is about 5/GTU.
- 2) The signals are integrated from Red Pixel to the defined 16 searching directions within 9GTU. In one GTU slice, the signals of 4 pixels which depend of the searching direction are integrated.
- 3) If the integrated value exceeds the threshold value, the trigger is issued.

With this trigger method, the energy threshold of the UHECR becomes about a half[5].

### 4. Acknowledgements

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### References

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